

Physics I - Demo Lab  
Magnetic Deflection of Electrons and  
Charge/Mass ratio

Description

A special vacuum tube is equipped with an electron "gun" which fires electrons toward a graticule/phosphor screen supported at an angle so that the electron path is visible. The electron beam may be deflected inside the tube by the application of electric or magnetic fields. This device works on the same principle as a TV picture tube: electron gun, phosphor screen, and magnetic deflection coils. An oscilloscope tube also works on the same principle.

By measuring the amount of electric or magnetic deflection, knowing the energy of the electrons, and the magnitude of the deflecting fields, the specific charge per unit mass of electrons, ( $e/m$ ), may be determined.  $e$  is the charge of the electron in Coulombs and  $m$  is the mass in kg.

Electric and magnetic deflection - Qualitative

The nature of electric and magnetic deflection will be demonstrated with fields produced by the electrostatic generator and permanent magnets. Verbally describe in your notes the nature of the two types of deflections with regard to the direction of the applied fields.

Magnetic Deflection - Quantitative To determine the charge/mass ratio, the magnetic field will be produced by two coils in a Helmholtz configuration. The separation of the two coils is equivalent to the radius of each coil. This arrangement produces a relatively uniform magnetic field over a large volume. The magnetic field from Helmholtz coils of radius,  $a$  (in meters), number of turns in each coil,  $n$ , is given by the expression:

$$B = \left[ \frac{32 \times 10^{-7} \pi}{5\sqrt{5}} \times \frac{n}{a} \right] I \quad (1)$$

The units of  $B$  are N/(amp m). The quantity in parentheses may be rewritten as a constant  $A$ . Thus the equation (1) may be written as

$$B = AI \quad (2)$$

For the coils available, determine  $a$ , the number of turns,  $N$ , and calculate  $A$ .

The electrons in the gun of the tube get their energy from a high voltage  $V$  (several thousand volts). The magnetic field causes the electron to follow a circular path of radius  $r$  measured in m. The electrons in the vacuum tube follow the dynamics of Newton's Laws. The dynamics of the forces yield the following expression for the specific charge:

$$\frac{e}{m} = \frac{2V}{r^2 B^2} \quad (3)$$

This equation is derived in the appendix.

The radius of curvature of the electron's orbit is obtained from a photograph of the orbit on the x-y grid of the graticule. Project a digital image of the photograph on the whiteboard and enter the coordinates for 3 points (in cm) evenly spaced on the circle. The matlab program MagOrbit presents a template for the student to enter the coordinates (in cm) and the program calculates the radius of the orbit. Note: the radius of the orbit is displayed on the Matlab command window.

Procedure: For a fixed value of the gun voltage,  $V$ , (about 4000 volt), adjust the Helmholtz current,  $I$ , so that the beam is deflected noticeably upwards by about 2 cm at the horizontal position of about 8 cm. If the curvature is too small, the precision of the measurement of the radius is severely compromised. Photograph the image with a digital camera – taking several photos to assure a good image. Reverse the Helmholtz current so that the beam deflects downward and obtain another photo. Record the photos serial numbers. Repeat for a second Helmholtz current that deflects the beam about 4 cm – both upwards and downwards.

Display the photographs of the orbits and read 3 x-y coordinates for each orbit. Enter the coordinates in the Matlab program MagOrbit to obtain the radius of the orbits.

Using Eq. 3 above, calculate the  $e/m$  for the electron for each orbit analyzed. Be sure to use SI units. Average the results to give the overall average and compare with the standard value.

## APPENDIX

Derivation of magnetic deflection

Magnetic force on electron traveling with velocity  $v$  perpendicular to magnetic field  $B$ :

$$F_M = evB \tag{A-1}$$

Equate the Magnetic force,  $F_M$ , with centripetal force

$$evB = \frac{mv^2}{r}$$

or

$$\frac{e}{m} = \frac{v}{rB} \tag{A-2}$$

Conservation of energy for gun voltage  $V$  gives:

$$eV = \frac{mv^2}{2} \tag{A-3}$$

or

$$v = \sqrt{2V \frac{e}{m}} \tag{A-4}$$

Substitution of (A-4) into (A-2) gives:

$$\frac{e}{m} = \frac{1}{rB} \sqrt{2V \left( \frac{e}{m} \right)}$$

$$\left( \frac{e}{m} \right)^2 = \frac{1}{r^2 B^2} 2V \left( \frac{e}{m} \right)$$

$$\frac{e}{m} = \frac{2V}{r^2 B^2} \tag{A-5}$$